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(54) ANNULUS SEAL UTILIZING ENERGIZED DISCRETE SOFT INTERFACIAL SEALING ELEMENTS

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E21B 33/04 (2006.01)

(52) **U.S. Cl.**
CPC ***E21B 33/03*** (2013.01); ***E21B 33/04*** (2013.01)

(58) **Field of Classification Search**
USPC 166/368, 378, 379, 88.1, 192, 180; 175/324; 277/308, 316, 328–329, 337, 277/530–531, 647, 626–627
See application file for complete search history.

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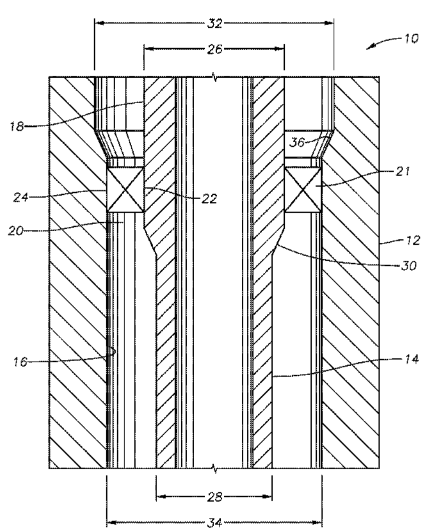
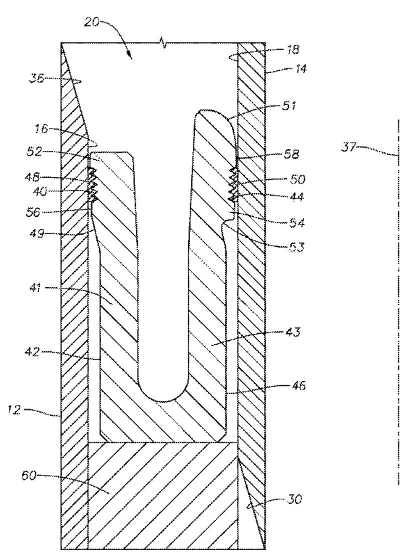
(57) **ABSTRACT**

A seal assembly for sealing an annulus between inner and outer wellhead members includes an energizer ring formed of a high strength elastic material having inner and outer legs. An annular inner recess with grooves on its base is formed on an inward facing surface of the inner leg. An inner diameter seal ring formed of an inelastic material engages the grooves of the inner recess. An annular outer recess with grooves on its base is formed on an outward facing surface of the outer leg. An outer diameter seal ring formed of an inelastic material engages the grooves of the outer recess. When the energizer ring is coaxially inserted in the annulus, the inner diameter seal ring is compressively and permanently deformed into sealing contact with the inner wellhead member, and the outer diameter seal ring is compressively and permanently deformed into sealing contact with the outer wellhead member.

23 Claims, 8 Drawing Sheets





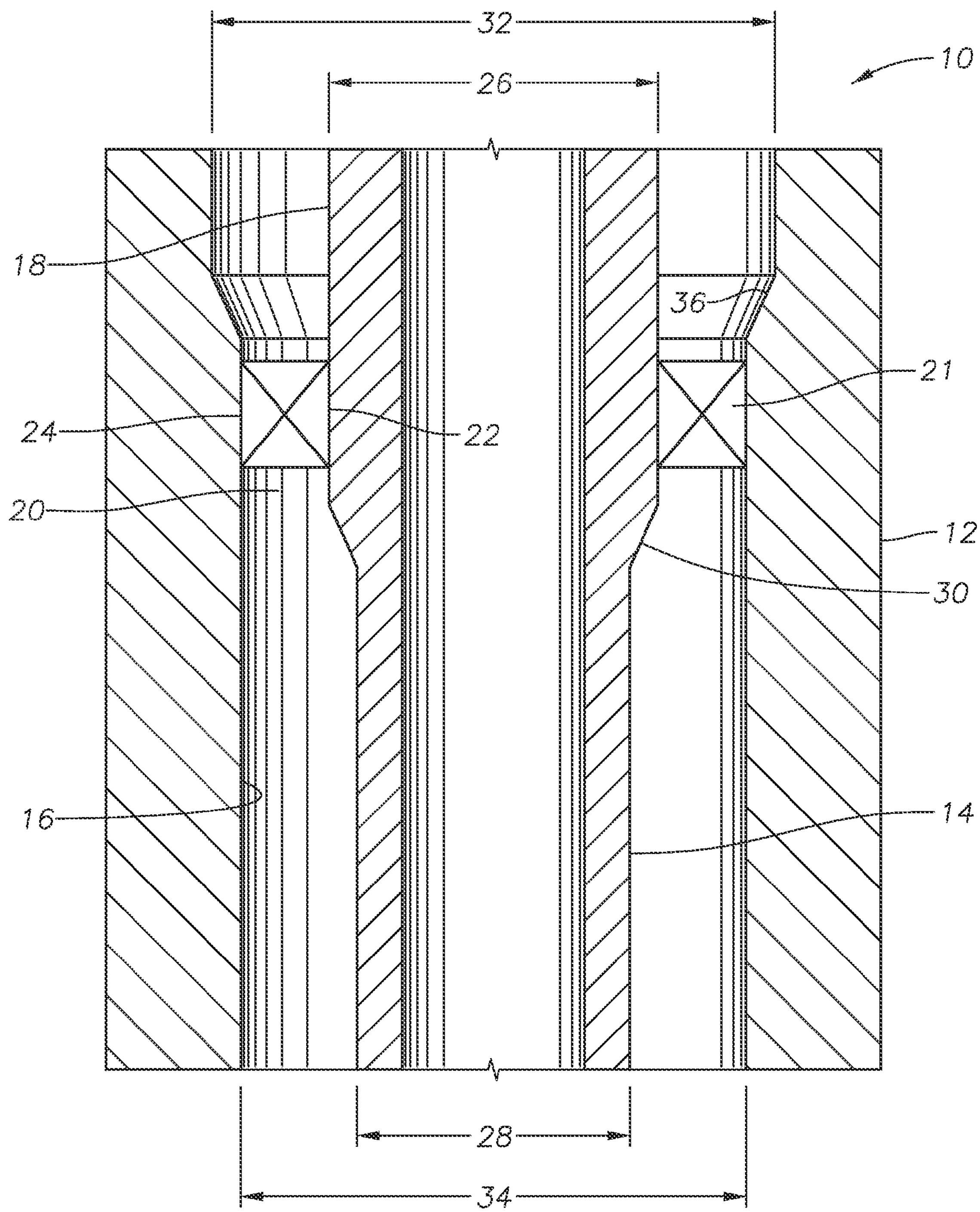


Fig. 1

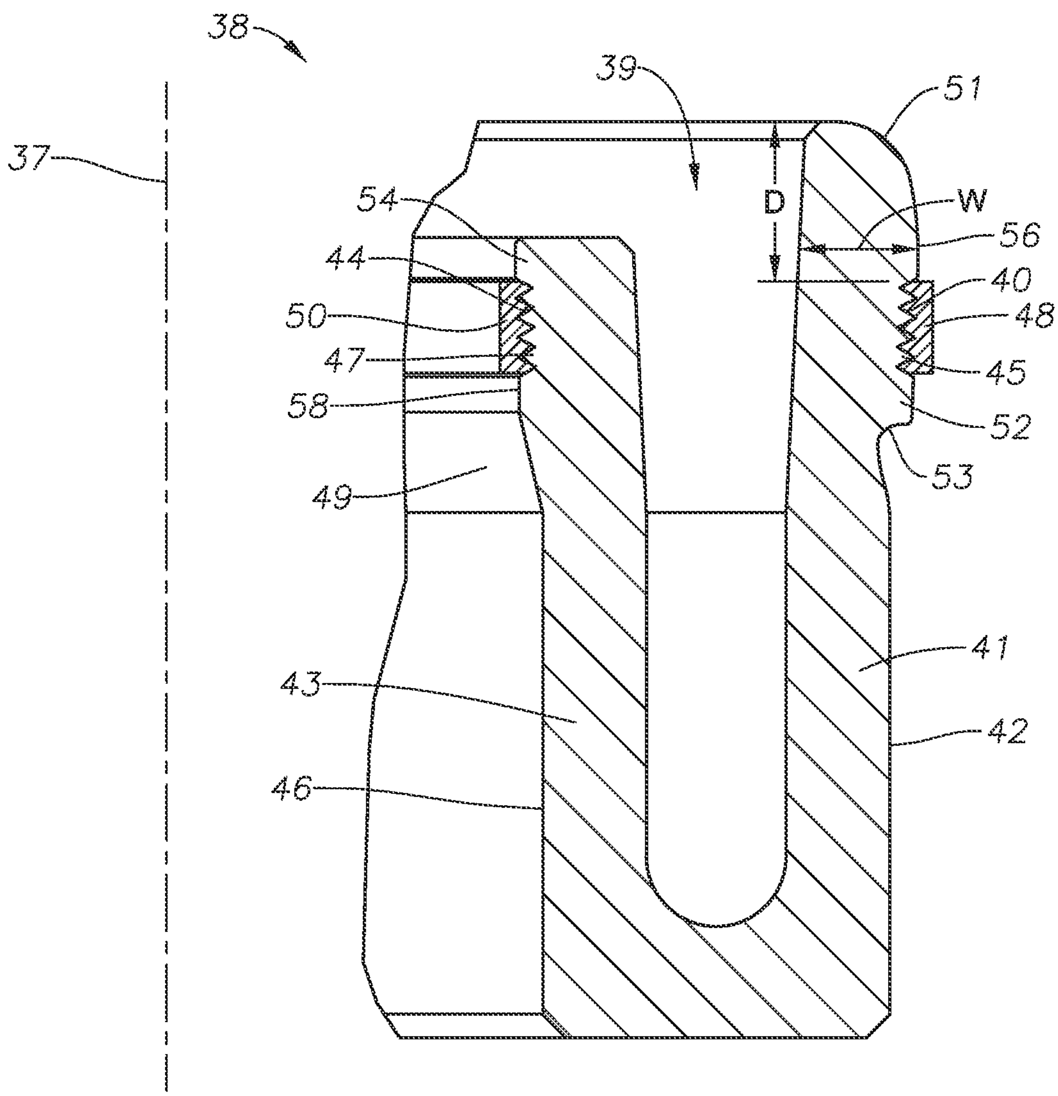


Fig. 2A

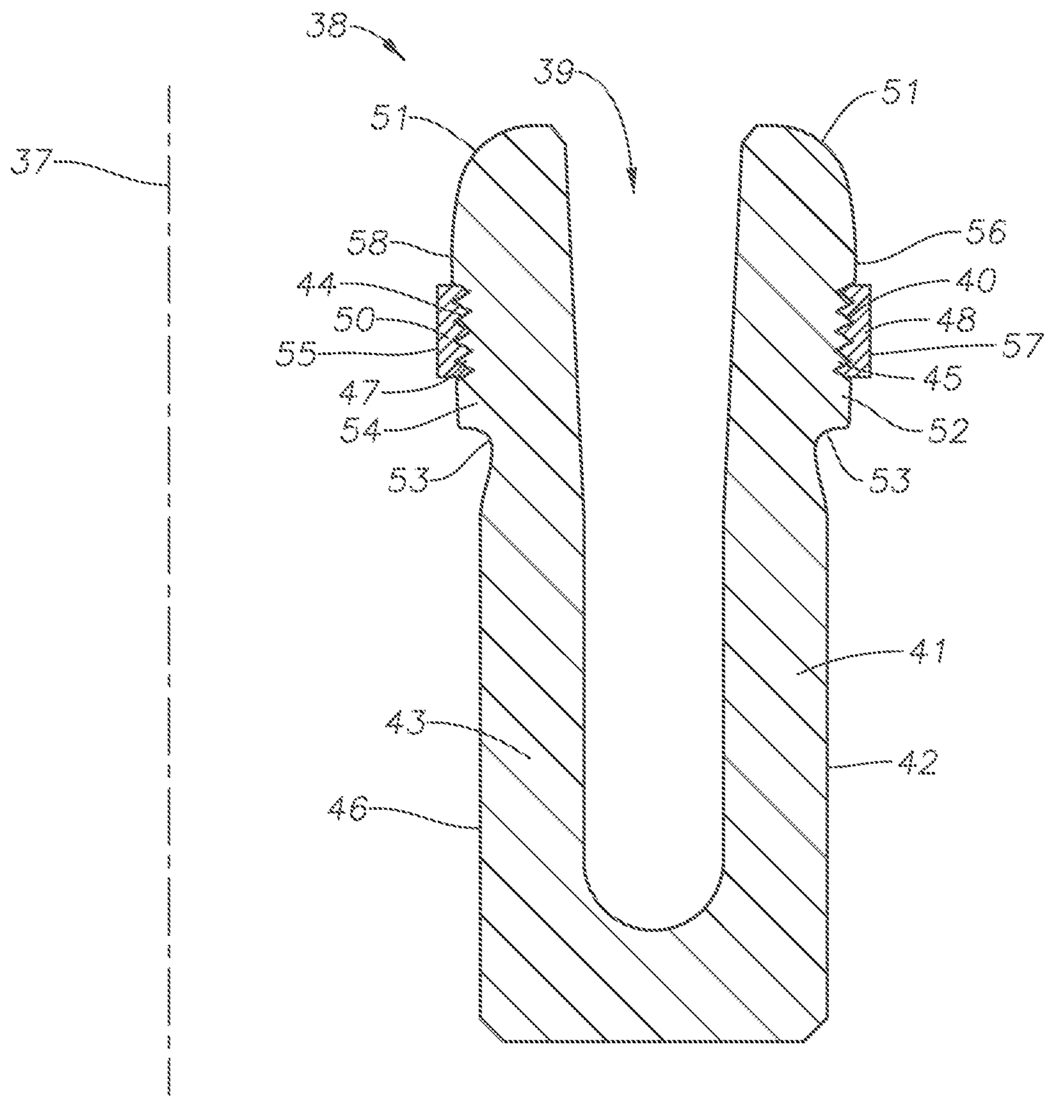


Fig. 2B

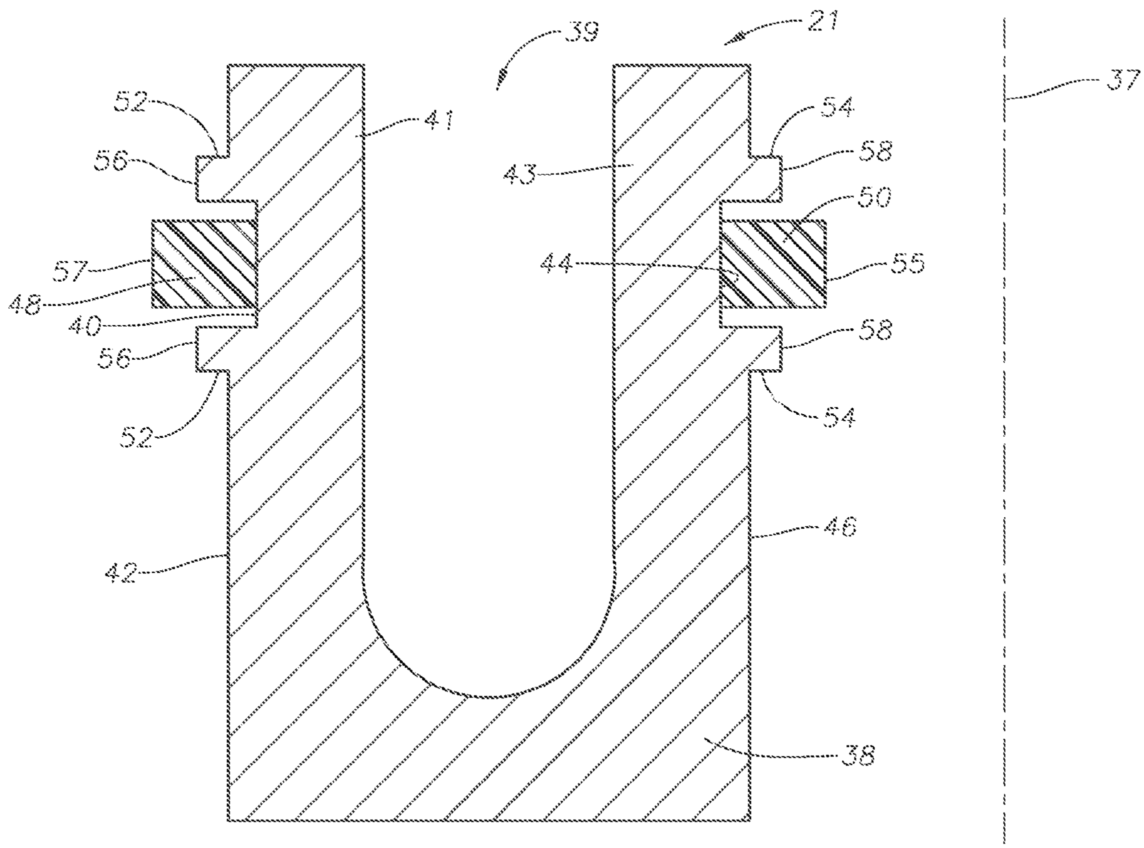


Fig. 2C

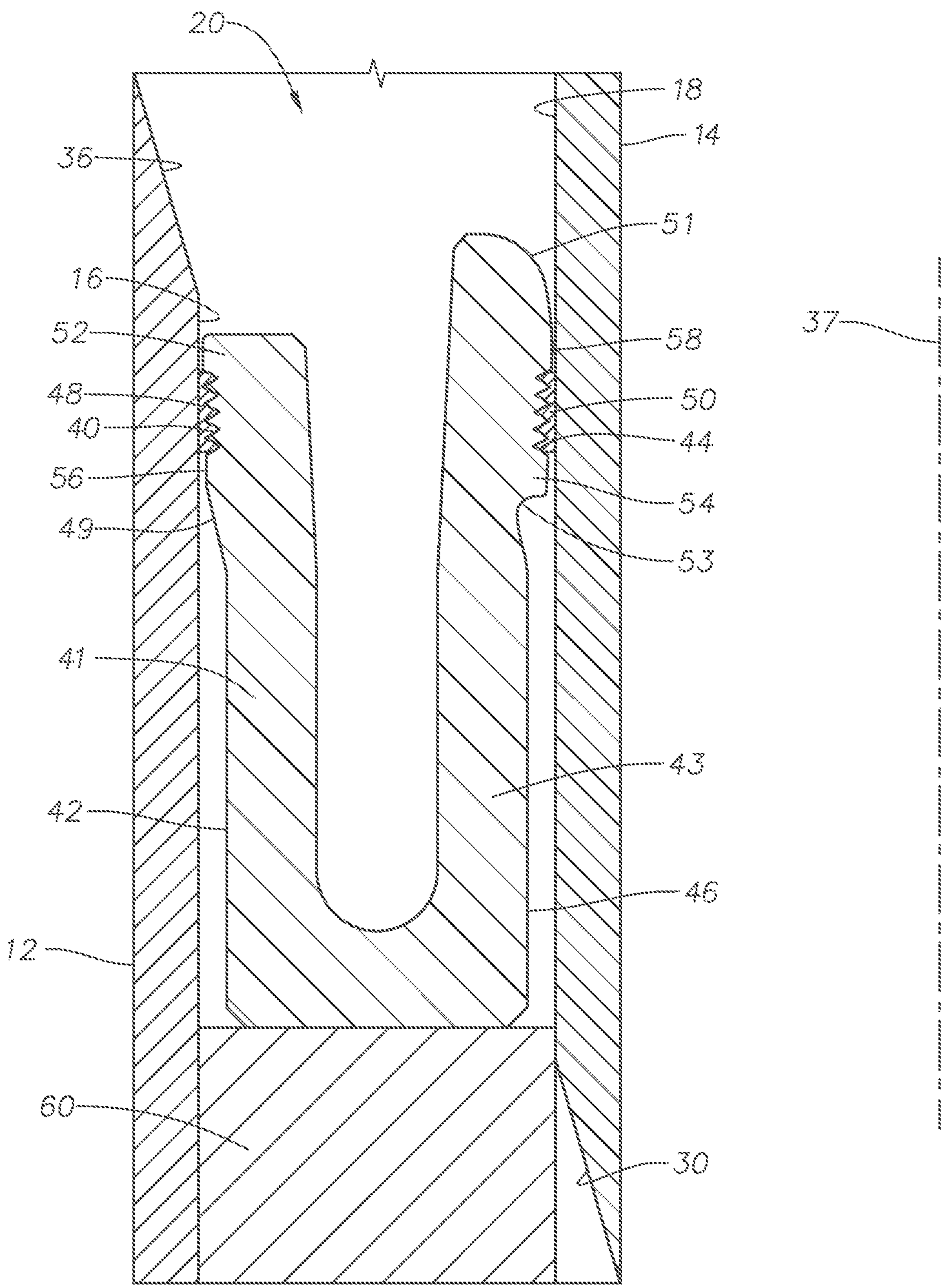


Fig. 3

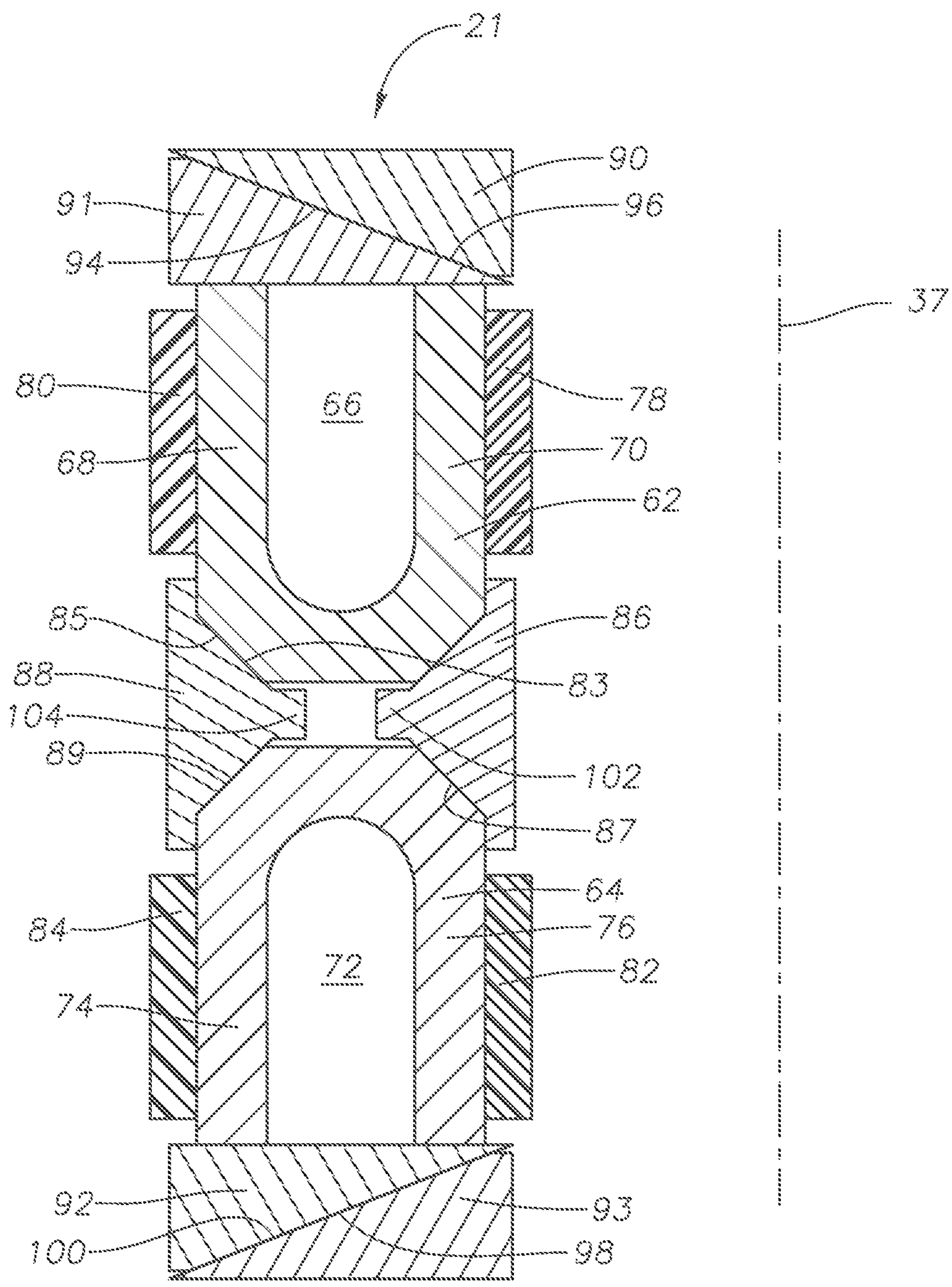

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Fig. 4

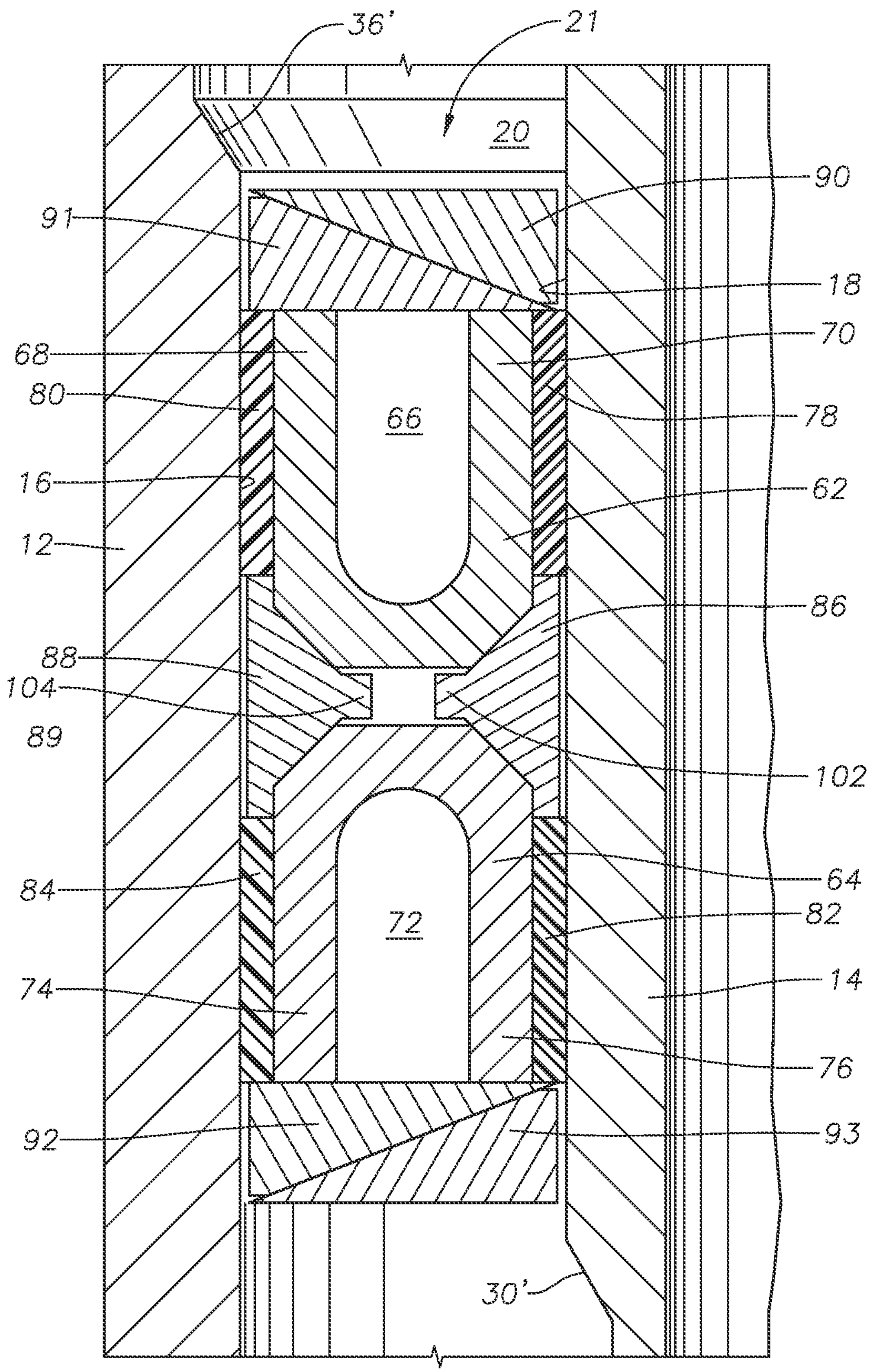
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Fig. 5

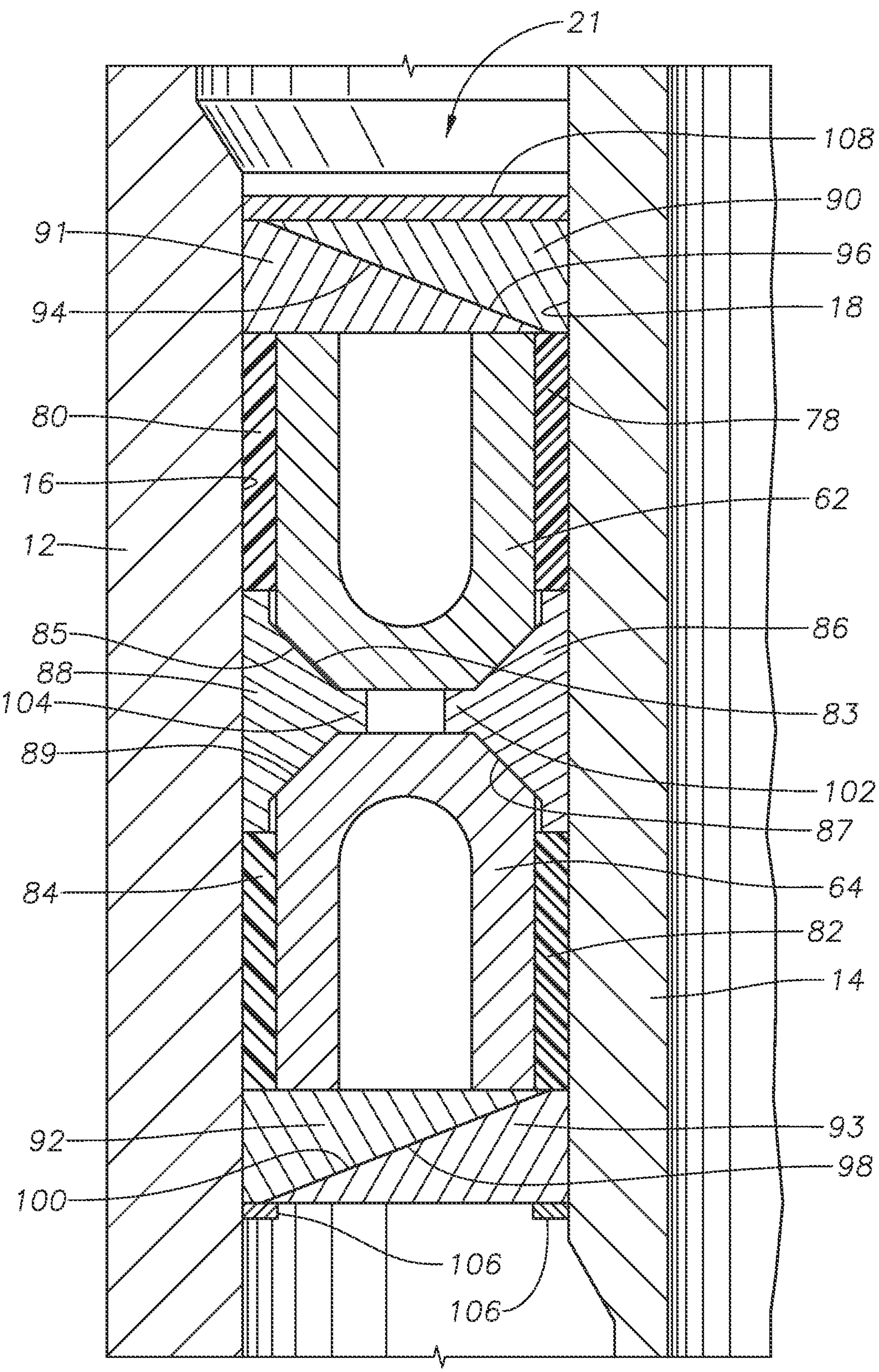
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Fig. 6

ANNULUS SEAL UTILIZING ENERGIZED DISCRETE SOFT INTERFACIAL SEALING ELEMENTS

CROSS REFERENCE TO RELATED APPLICATION

This application is a continuation-in-part of and claims priority to and the benefit of U.S. patent application Ser. No. 13/176,312, titled "Annulus Seal Utilizing Energized Discrete Soft Interfacial Sealing Elements," filed Jul. 5, 2011, the full disclosure of which is hereby incorporated herein by reference in its entirety for all purposes.

BACKGROUND OF THE DISCLOSURE

1. Field of the Disclosure

This disclosure relates in general to wellhead assemblies and in particular to seal assemblies for sealing between inner and outer wellhead members.

2. Description of the Related Art

Seals are used between inner and outer wellhead tubular members to contain internal well pressure. The inner wellhead member may be a casing hanger that supports a string of casing extending into the well for the flow of production fluid. The casing hanger lands in an outer wellhead member, which may be a wellhead housing, a Christmas tree, or a casing head. A packoff (or other seal assembly) seals the annulus between the casing hanger and the outer wellhead member. Alternately, the inner wellhead member can be a tubing hanger located in a wellhead housing and secured to a string of tubing extending into the well. A pack off (or other seal assembly) seals the annulus between the tubing hanger and the wellhead housing. In another alternative design, the inner wellhead member may be an isolation sleeve, such as might be used to isolate high pressure, abrasive fracturing fluids from certain portions of the wellhead. A packoff (or other seal assembly) seals the annulus between the isolation sleeve and the outer wellhead member.

A variety of annulus seals of this nature have been employed. Conventional annulus seals include, for example, elastomeric and partially metal and elastomeric rings. Prior art subsea stab type seals may utilize elastomeric materials which are compressed into an interference fit annulus. These are simple designs, easy to install, retain a reasonable constant load when unpressurised over time due to their inherent elasticity and are soft enough to flow and seal on minor defects. However such materials have a limited range of use in terms of temperature and fluid compatibility. They may swell and degrade mechanically in certain fluid environments, such as those found in many wellheads, and can suffer from explosive failure if subjected to rapidly decreasing pressure in a gas environment.

Prior art seal rings made entirely of metal for forming metal-to-metal seals are also employed. In order to cope with internal stressing remote from the interfaces, metal seals of the prior art are made from hard high strength materials which make sealing at the interface difficult and require generating of huge loads to provide any degree of damage tolerance. This in turn will itself cause damage to the same surfaces. To overcome this, coatings in the form of spray coatings or plating or melted inlays, such as brazing, have been used to bond a secondary softer material to the metal seal. These coatings are often difficult to apply, costly, inefficient in material usage, tend to increase the hardness of the sprayed material and are typically difficult to apply thick enough to provide the volume of material required to seal on serious defects.

A third option for the prior art has been to use inelastic thermoplastic materials such as polytetrafluoroethylene, or molded graphite for the sealing apparatus. These do not have any inherent elasticity and so require some secondary parts, such as internal springs, to provide an elastic response to the changing environment that ensures the seal retains a reasonable constant load when unpressurised over time and so ensuring a seal is maintained at all times. Due to the low strength of thermoplastic materials they generally cannot sustain the loads required to cause significant plastic flow at the interface and so do not tend to seal well on damaged surfaces.

Therefore while metal or inelastic materials allow a much wider temperature range, do not swell or degrade mechanically in most fluid environments and do not suffer from explosive gas decompression, they do represent many other technical problems, most notably an inability to seal on damaged surfaces. Damage to subsea parts cannot be fully monitored or controlled and therefore seal failure due to damaged surfaces represents a significant cost risk when running equipment subsea.

SUMMARY OF THE DISCLOSURE

There is a need for an annulus seal that would maintain a seal on serious surface defects, operate over a much wider temperature range, does not swell or degrade mechanically in most fluid environments, does not suffer from explosive gas decompression and can be easily and cheaply manufactured. In view of the foregoing, various embodiments of the present disclosure advantageously provide seal assemblies to address shortfalls of the prior art. Various embodiments of the present application use soft inelastic materials in a situation where the seal is highly loaded, by removing the inelastic material from the highly stressed unsupported areas and replacing it with a high strength energizer. Alternative embodiments use thick soft metallic materials, in fully annealed condition if required, with no need for a metallurgical or other type of bond to the base component.

More specifically, the current disclosure provides a seal assembly for sealing an annulus between inner and outer wellhead members. The seal assembly includes an energizer ring formed of a high strength elastic material having inner and outer legs and a central axis. An annular inner recess is formed on an inward facing surface of the inner leg, the inner recess having grooves on a base the inner recess. An inner diameter seal ring is formed of an inelastic material, the inner diameter seal ring engaging the grooves of the inner recess. An annular outer recess is formed on an outward facing surface of the outer leg, the outer recess having grooves on a base of the outer recess. An outer diameter seal ring is formed of an inelastic material located in the outer recess, the outer diameter seal ring engaging the grooves of the outer recess. Wen the energizer ring is coaxially inserted in the annulus, the inner diameter seal ring is compressively and permanently deformed into sealing contact with the inner wellhead member, and the outer diameter seal ring is compressively and permanently deformed into sealing contact with the outer wellhead member.

In other embodiments of the current disclosure a wellhead assembly includes an outer wellhead member having a bore and an axis. An inner wellhead member is located in the bore defining an annulus between the inner and outer wellhead members. An energizer ring is formed of an elastic material and has a base and inner and outer legs, each leg extending axially from the base to a free end that biases in opposing radial directions respectively against the inner and outer wellhead members. There is an open slot between the legs. The inner leg has an inward facing surface with an annular inner band located on and protruding inward from the inward facing surface of the inner leg. An annular inner recess is formed in the inner band, the inner annular recesses having grooves on a base of the inner recess. An annular inner diameter seal ring is formed of an inelastic material and located in the inner recess and engages the grooves of the inner recess. The outer leg has an outward facing surface with an annular outer band located on and protruding outward from the outward facing surface of the outer leg. An annular outer recess is formed in the outer band, the outer annular recesses having grooves on a base of the outer recess. An annular outer diameter seal ring is formed of an inelastic material and located in the outer recess. The outer diameter seal ring engages the grooves of the outer recess.

Yet other embodiments of the current disclosure prove a method for sealing an annulus between inner and outer wellhead members. The method involves providing a seal assembly that includes an energizer ring formed of a high strength elastic material having inner and outer legs and a central axis, an annular inner recess formed on an inward facing surface of the inner leg having grooves on a base of the inner recess, an inner diameter seal ring formed of an inelastic material engaging the grooves of the inner recess, an annular outer recess formed on an outward facing surface of the outer leg having grooves on a base of the outer recess, and an outer diameter seal ring formed of an inelastic engaging the grooves of the outer recess. The method also includes inserting the seal assembly into the annulus so that the seal rings contact inner and outer surfaces of the annulus, plastically deforming the seal rings into sealing engagement between the legs and the inner and outer surfaces by a spring force in the legs.

BRIEF DESCRIPTION OF THE DRAWINGS

So that the manner in which the features and advantages of the disclosure, as well as others which will become apparent, may be understood in more detail, a more particular description of the disclosure briefly summarized above may be had by reference to the embodiments thereof which are illustrated in the appended drawings, which form a part of this specification. It is to be noted, however, that the drawings illustrate only various embodiments of the disclosure and are therefore not to be considered limiting of the disclosure's scope as it may include other effective embodiments as well.

FIG. **1** is a sectional view of portions of a wellhead assembly providing a annulus seal;

FIG. **2**A is a sectional view of a portion of a seal assembly according to an embodiment of the present disclosure;

FIG. **2**B is a sectional view of a portion of the seal assembly according to an alternative embodiment of the present disclosure.

FIG. **2**C is a sectional view of a portion of the seal assembly according to an alternative embodiment of the present disclosure.

FIG. **3** is a sectional view of the seal assembly of FIG. **2**A located within a wellhead assembly;

FIG. **4** is a sectional view of a portion of a seal assembly according to an alternative embodiment of the present disclosure; and

FIG. **5** is a sectional view of the seal assembly of FIG. **4** located within a wellhead assembly.

FIG. **6** is an additional sectional view of the seal assembly of FIG. **4** located within a wellhead assembly.

DETAILED DESCRIPTION

The present disclosure will now be described more fully hereinafter with reference to the accompanying drawings, which illustrate embodiments of the disclosure. Embodiments of this disclosure may, however, be in many different forms and should not be construed as limited to the illustrated embodiments set forth herein. Rather, these embodiments are provided so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art. Like numbers refer to like elements throughout. Prime notation, if used, indicates similar elements in alternative embodiments.

FIG. **1** illustrates, for example, portions of a wellhead assembly **10** including a seal assembly **21**, which may be a seal assembly according to any of the embodiment of the present application. The wellhead assembly **10** can include an outer wellhead member or tubular **12** affixed at an upper end of a wellbore (not shown) and coaxially circumscribing an inner wellhead member or tubular **14**. The outer tubular **12** may be, for example, a high-pressure wellhead housing or a casing hanger. The inner tubular **14** may be, for example, a casing hanger, casing, tubing hanger, production tubing, or an isolation sleeve.

Inner tubular **14** transitions from an upper region with a larger outer diameter **26** higher within the wellhead assembly **10**, to a lower region with a smaller outer diameter **28** lower within the wellhead assembly **10** through a downward facing shoulder **30**. Outer tubular **12** transitions from an upper region with a larger inner diameter **32** higher within the wellhead assembly to a lower region with a smaller inner diameter **34** lower within the wellhead assembly **10** through an upward facing shoulder **36**.

The spaced apart distance between the respective inner surface **16** of outer tubular **12** and outer diameter surface **18** of the inner tubular **14**, respectively form an annulus **20**. Within annulus **20** is seal assembly **21**. Seal assembly **21** is ring shaped. The diameter of the opening in the center of the ring shaped assembly **21** is sized so that inner diameter sealing surface **22** of seal assembly **21** makes contact with the outer diameter surface **18** of the inner tubular **14**. The outer diameter of the ring shaped assembly **21** is sized so that outer diameter sealing surface **24** of seal assembly **21** makes contact with inner surface **16** of outer tubular **12**. Embodiments of seal assembly **21** are shown in FIGS. **2**-**6**.

Turning to FIGS. **2**A-**2**C and **3**, the seal assembly **21** may comprise an energizer **38**. Energizer **38** is a ring shaped member with a central axis **37**. Energizer **38** is shown as having a single "U" cross sectional shape, creating a downward or upward facing (as applicable) internal slot or groove **39**. Internal groove **39** results in energizer **38** having an outer leg **41** and an inner leg **43**, defined by the shape of internal groove **39**. Each of the legs **41**, **43** has a base end proximate to the closed end of internal groove **39** and a free end opposite its base end. Each of the legs **41**, **43** has an exterior surface that faces away from the other leg and an interior surface that faces towards the other leg. Although the legs **41**, **43** in the figures of this disclosure have been identified as being either an outer leg **41** or an inner leg **43**, in other embodiments, the shape and position of the legs may be reversed. Although the energizer **38** is shown in FIGS. **2**A-**2**C and **3** as a upward facing "U" shape, the orientation of the "U" shape may be reversed in alternative embodiments.

Energizer **38** has an annular outer circumferential recess **40** on the outer surface **42** of energizer **38** and an annular inner circumferential recess **44** on the inner surface **46** of energizer **38**. Outer recess **40** contains an outer diameter seal ring **48** and inner recess **44** contains an inner diameter seal ring **50**. In the embodiments of FIGS. **2**A-**2**B and **3**, outer recess **40** has grooves **45** formed on an outward facing base of the outer recess **40** and inner recess **44** has grooves **47** formed on an inward facing base of the inner recess **44**. Outer diameter seal ring **48** engages the grooves **45** of the outer recess **40** to assist in maintaining the position of outer diameter seal ring **48** within outer recess **40** during installation of the seal assembly **21** into the wellhead assembly **10**. Similarly, the inner diameter seal ring **50** engages the grooves **47** of the inner recess **44** to assist in maintaining the position of inner diameter seal ring **48** during installation of the seal assembly **21** into the wellhead assembly **10**.

Each of the legs **41**, **43** has an enlarged portion proximate to the free end. The enlarged portion has a radial width greater than the radial with of the leg **41**, **43** proximate to the base end. Outer recess **40** and inner recess **44** are formed in the enlarged portion of legs **41**, **43**, respectively. The enlarged portions define circumferential bands or protrusions **52** that project outward from outer surface **42** of energizer **38** above and below outer circumferential recess **40**. Similarly, the enlarged portions define circumferential bands or protrusions **54** that project inward from inner surface **46** of energizer **38** above and below inner circumferential recess **44**. Protrusions **52**, **54** have circumferential end surfaces **56**, **58**, respectively. At least an axial length of end surfaces **56**, **58** are cylindrical surfaces that are concentric with axis **37**. Annular recesses **40**, **44** are located within each of the bands **52**, **54** respectively. In certain embodiment, annular recesses **40**, **44** are positioned so that for at least one of the legs **41**, **43**, the largest radial width W of the leg **41**, **43** is less than the axial distance D between the free end of the leg **41**, **43** and the recess **40**, **44** (FIG. **2**A).

In the embodiment of FIGS. **2**A-**2**B and **3**, the interior surface of each of the legs **41**, **43** can include two separately oriented surfaces. Proximate the base end of each of the legs **41**, **43**, the interior surface of each of the inner and outer legs **41**, **43** is a cylindrical surface that is coaxial with axis **37**. Proximate to the free end of each of the legs **41**, **43**, the interior surface of each of the inner and outer legs **41**, **43** is conical, having a larger diameter proximate to the free end of legs **41**, **43** when the energizer **38** is in a relaxed position. In other embodiments, such as that of FIG. **2**C, the interior surface of each of the inner and outer legs **41**, **43** can be a single annular surface that is coaxial with axis **37**.

As shown in the embodiments of FIGS. **2**A and **3**, inner leg **43** is a longer leg and outer leg **43**-**41** is a shorter leg such that the inner leg **43** has a axial length that is greater than the axial length of outer leg **41**. The exterior surface of outer leg **41** tapers gradually where the radial width of the outer leg **41** increases to the enlarged portion of bands **52**, defining a conical exterior surface **49** of the outer leg **41**. This conical exterior surface **49** can act as a lead in surface to slidingly engage the outer tubular **12** when the seal assembly **21** is installed in the wellhead assembly **10**.

The exterior surface of inner leg **43** has a large radius of curvature **51** extending from the free end towards the inner recess **44**. The large radius of curvature **51** can be a continuous curving surface made up of a series of surfaces with different radii. At least one surface of radius of curvature **51** has a radius with a length that is greater than the radial width of inner leg **43**, such that the center point of such surface is outside of the outer inner leg **43**. The large radius of curvature **51** can act as a lead in surface to slidingly engage the inner tubular **14** when the seal assembly **21** is installed in the wellhead assembly **10**. In such embodiments, the seal assembly **21** is slidingly engaged in one direction by the outer tubular **12** and is slidingly engaged in an opposite directly by the inner tubular **14**. The exterior surface of inner leg **43** has a undercut recess **53** located adjacent to the enlarged portion, where the bands **54** meet the inner surface **46**. The undercut recess **53** can provide stress relief when the seal assembly **21** is installed in the wellhead assembly **10**.

In other embodiments, the inner and outer legs **41**, **43** can be of substantially equal length and have large radii of curvature **51** on both the inner and outer legs **41**, **43**, for slidingly engaging both the inner and outer tubulars **12**, **14** in the same direction when the seal assembly **21** is inserted in the wellhead assembly **10** (FIG. **2**B). In other embodiments the inner and outer legs **41**, **43** can be of substantially equal length and both have conical exterior surfaces **49** for slidingly engaging both the inner and outer tubulars **12**, **14** in the same direction when the seal assembly **21** is inserted in the wellhead assembly **10** (not shown).

Seal rings **48**, **50** are shown with a generally rectangular cross section with a grooved surface that engages the grooves **45**, **47** of annular recess **40**, **44** (FIGS. **2**A-**2**B and **3**) or as solid square in cross section (FIG. **2**C) but they may have other alternative cross sections, such as rectangular, semi-circular, circular, oval, or other workable shape. Seal rings **48**, **50** may be molded in place, extruded, machined complete, compression formed from wire and joined at the ends or fabricated by other known methods. In the embodiment of FIG. **2**C, when energizer **38** is not positioned within annulus **20**, the axial height of outer circumferential recess **40** is bigger than the axial height of outer diameter seal ring **48** and the axial height of inner circumferential recess **44** is bigger than the axial height of inner diameter seal ring **50**. This allows room for seal rings **48**, **50** to expand in height when the width of the seal rings **48**, **50** is compressed, as shown in FIG. **3**, when seal assembly **21** is located within annulus **20**. Seal rings **48**, **50** are not fixed or bonded to energizer **38**. This avoids a complicated or costly bonding process, allows for easy replacement of the seal rings **48**, **50**, and allows the seal rings **48**, **50** to more readily flow into defects.

As show in FIG. **3**, when energizer **38**, is located within annulus **20**, outer seal ring **48** is in sealing engagement with inner surface **16** of outer tubular **12** and the energizer **38**. Inner seal ring **50** is in sealing engagement with outer diameter surface **18** of the inner tubular **14** and energizer **38**. Energizer **38** is positioned above downward facing shoulder **30** of inner tubular **14** and below upward facing shoulder **36** of outer tubular **12**. In alternative embodiments, shoulder **30** may be upward facing and shoulder **36** may be downward facing. In yet other alternative embodiments, shoulders **30**, **36** may both face upwards or both face downwards. Internal groove **39** of energizer **38** is open to the pressure of the well fluid contained within annulus **20**. In the embodiment of FIG. **3**, the pressure side is at the higher end of annulus **20** and therefore internal groove **39** opens upward. In alternative embodiment, the pressure side may be at the lower end of annulus **20**, in which case, the groove **39** would open downward. A retainer ring **60** is located below energizer **38** to limit downward movement of energizer **38** within annulus **20**.

Seal assembly **21** may be installed within annulus **20** with an interference between the inner surface **16** of outer tubular **12** and outer diameter surface **18** of the inner tubular **14**. In this case, the initial radial dimension of the energizer **38**, measured from end surface **56** to end surface **58** is larger than the distance between inner surface **16** of outer tubular **12** and the energizer **38**, outer diameter surface **18** of the inner tubular **14**. Similarly, the initial radial dimension from inner surface **55** of the inner diameter seal ring **50** to an outer surface **57** of the outer diameter seal ring **48** greater than a radial width of the annulus between inner surface **16** of outer tubular **12** and the outer diameter surface **18** of the inner tubular **14**. Therefore legs **41**, **43** of energizer **38** will have to deflect inward towards each other when inserted within annulus **20**.

This inward deflection of legs **41**, **43** of energizer **38** generate an outward radial elastic load. This will cause seal rings **48**, **50** to be compressed between inner surface **16** of outer tubular **12** and the energizer **38**, and the outer diameter surface **18** of the inner tubular **14** and energizer **38**, respectively.

The compressive forces causes plastic or permanent deformation of seal rings **48**, **50**, causing them to fill the recesses **40** and **44** and to seal with and fill any defects in outer tubular **12** and inner tubular **14**. The deformation of seal rings **48**, **50** is contained to the interior of recesses **40**, **44**, which act as anti-extrusion means. End surfaces **56**, **58** of protrusions **52** and **54** will become proximate to, and may contact, the inner surface **16** of outer tubular **12** and outer diameter surface **18** of the inner tubular **14**, respectively, to limit the outward radial forces on seal rings **48**, **50**. The combination of the elastic deformation of energizer **38** and plastic deformation of seal rings **48**, **50** creates a constant elastic contact pressure at each of the sealing interfaces which does not diminish with time or load history or temperature, and creates a seal at low pressure and also possibly at high pressure.

Alternatively, radial outward elastic load of energizer **38** may be created by the fluid pressure within annulus **20**. In this embodiment, the fluid pressure within annulus **20** and groove **39** will act on the inside surfaces of groove **39**, which is open to the pressure of the fluid contained within annulus **20**, applying a radial force on legs **41**, **43**. In the same manner as discussed above, this will cause seal rings **48**, **50** to be compressed between inner surface **16** of outer tubular **12** and the energizer **38**, and the outer diameter surface **18** of the inner tubular **14** and energizer **38**, respectively. As described above, the compression causes plastic or permanent deformation of seal rings **48**, **50**, causing them to fill the recesses **40** and **44**. In this case, a drop in pressure may cause a drop in elastic loading of the energizer **38**. Another alternative embodiment is to combine both an interference fit and fluid pressure loading on energizer **38**. In this embodiment, the energizer **38** and seal rings **48**, **50** will still maintain a seal in the event of a complete loss of fluid pressure, but the elastic forces of energizer **38** may be augmented by fluid pressure within annulus **20** and groove **39**.

Seal rings **48**, **50** are formed of soft inelastic materials and may be for example, a soft metal such as lead, tin, silver or alloys of these metals. Selection of the material to use will depend on the operating pressure to which the seal assembly **21** will be exposed and setting load required to push fit the seal. In alternative embodiments, other soft metals such as gold or tantalum can be used or the seal rings **48**, **50** could be formed of an inelastic thermoplastic, such as virgin polytetrafluoroethylene, filled polytetrafluoroethylene or polyetheretherketone, or other inert inelastic materials such as compression molded graphite. Seal rings **48**, **50** may alternatively be formed of other soft inelastic materials. An appropriate soft inelastic material will be selected so that seal rings **48**, **50** will flow readily into defects on the inner surface **16** of outer tubular **12** and the outer diameter surface **18** of the inner tubular **14** and create sufficient contact pressure on the surface of any such defect to create a seal when subjected to radial loading. Where there is no defect present the seal rings **48**, **50** will simply deform and flow upwards and downwards in the recesses **40**, **44** to fill the available space, while creating a seal on the defect free inner surface **16** of outer tubular **12** and the outer diameter surface **18** of the inner tubular **14**.

Energizer **38** is formed from material that is strong enough to withstand the internal fluid pressure within the annulus **20** as well as any internal loads generated by the interference fit between the energizer **38**, the inner surface **16** of outer tubular **12** and outer diameter surface **18** of the inner tubular **14**, without undergoing significant plastic deformation, which could limit the load that could be applied to energizer **38** or cause failure of energizer **38** and thus cause the seal assembly **21** to fail. Energizer **38** must therefore be made from material with higher strength or that is harder than the material used to make the seal rings **48**, **50**. Preferably, energizer **38** is made from a nickel based alloy or other corrosion resistant alloy. Where corrosion is not of concern, energizer **38** can be made from carbon steel.

In an alternative embodiment, as shown in FIG. **4**, the seal assembly may comprise two energizers, including a primary energizer **62** and a backside energizer **64**. Energizers **62**, **64** are shown as single "U" section shaped rings. Primary energizer **62** has an upward facing internal slot or groove **66**, which results in energizer **62** having an outer leg **68** and an inner leg **70**, defined by the shape of internal groove **66**. Backside energizer **64** has a downward facing internal slot or groove **72**, which results in energizer **64** having an outer leg **74** and an inner leg **76**, defined by the shape of internal groove **72**. Energizers **62**, **64** may have alternative shaped cross sections.

Primary inner diameter seal ring **78** is located external to leg **70** of primary energizer **62** and primary outer diameter seal ring **80** is located external to leg **68** of primary energizer **62**. Backside inner diameter seal ring **82** is located external to leg **76** of backside energizer **64** and backside outer diameter seal ring **84** is located external to leg **74** of backside energizer **64**. Seal rings **78**, **80**, **82**, **84** are shown with a solid rectangular cross section but they may have other alternative cross sections, such as square, semi-circular, circular, oval, or other workable shape. Seal rings **78**, **80**, **82**, **84** may be extruded, machined complete, compression formed from wire and joined at the ends or fabricated by other known methods.

An inner intermediate anti-extrusion ring **86** is located below primary inner diameter seal ring **78** and above backside inner diameter seal ring **82**. A lateral portion **102** of inner intermediate anti-extrusion ring **86** extends between primary energizer **62** and backside energizer **64**. An outer intermediate anti-extrusion ring **88** is located below primary outer diameter seal ring **80** and above backside outer diameter seal ring **84**. A lateral portion **104** of outer intermediate anti-extrusion ring **88** extends between primary energizer **62** and backside energizer **64**.

In the embodiment of FIG. **4**, intermediate anti-extrusion rings **86**, **88** are generally wedge shaped with upward facing shoulders **83** which engage downward facing wedge surfaces or shoulders **85** of primary energizer **62**. Downward facing wedge surface or shoulder **87** of anti-extrusion rings **86**, **88** engage upward facing shoulders **89** of backside energizer **64**.

Primary anti-extrusion rings **90**, **91** are located above primary seal rings **78**, **80** and backside anti-extrusion rings **92**, **93** are located below backside seal rings **82**, **84**. In the embodiment of FIG. **4**, the primary anti-extrusion rings **90**, **91** consist of a pair of rings with a wedge shaped cross section. Outer primary anti-extrusion ring **90** has an upper surface which is essentially horizontal and an angled downward facing surface **94**. Inner primary anti-extrusion ring **91** has a lower surface which is essentially horizontal and an angled upward facing surface **96**. Downward facing surface **94** of outer primary anti-extrusion ring **90** engages upward facing surface **96** of Inner primary anti-extrusion ring **91**. Inner backside anti-extrusion ring **92** has an upper surface which is essentially horizontal and an angled downward facing surface **98**. Outer primary anti-extrusion ring **93** has a lower surface which is essentially horizontal and an angled upward facing surface **100**. Downward facing surface **98** of inner backside anti-extrusion ring **92** engages upward facing surface **100** of outer backside anti-extrusion ring **93**.

Before being inserted in an annulus, the inner diameter of the inner diameter seal rings **78**, **82** is smaller than the inner diameter of the primary anti-extrusion rings **90**, **91** intermediate inner anti-extrusion ring **86**, and backside anti-extrusion rings **92**, **93**. Similarly, the outer diameter of the outer diameter seal rings **80**, **84** is larger than the outer diameter of primary anti-extrusion rings **90**, **91** intermediate outer anti-extrusion ring **88**, and backside anti-extrusion rings **92**, **93**. In addition, the height of the seal rings **78**, **80** is shorter than the distance between the primary anti-extrusion rings **90**, **91** and the intermediate anti-extrusion rings **86**, **88**. The height of the seal rings **82**,**84** is shorter than the distance between the intermediate anti-extrusion rings **86**, **88**, and the backside anti-extrusion rings **92**, **93**. This allows room for seal rings **78**, **80**, **82**, **84** to expand in height when the width of the seal rings **78**, **80**, **82**, **84** is compressed, as shown in FIG. **5**, when seal assembly **21** is located within annulus **20**. Seal rings **78**, **80**, **82**, **84** are not fixed or bonded to energizers **62**, **64**. This avoids a complicated or costly bonding process, allows for easy replacement of the seal rings **78**, **80**, **82**, **84**, and allows the seal rings **78**, **80**, **82**, **84** to more readily flow into defects.

When seal assembly **21** of FIG. **5** is positioned within an annulus **20**, primary outer diameter seal ring **80**, is in sealing engagement with inner surface **16** of outer tubular **12** and with the primary energizer **62**. Primary inner diameter seal ring **78** is in sealing engagement with outer diameter surface **18** of the inner tubular **14** and with primary energizer **62**. Backside outer diameter seal ring **84**, is in sealing engagement with inner surface **16** of outer tubular **12** and with the backside energizer **64**. Backside inner diameter seal ring **82** is in sealing engagement with outer diameter surface **18** of the inner tubular **14** and with backside energizer **64**. Seal assembly **21** is positioned above downward facing shoulder **30'** of inner tubular **14** and below upward facing shoulder **36'** of outer tubular **12**.

As shown in FIG. **6**, when seal assembly **21** is fully set within annulus **20**, backside anti-extrusion rings **92**, **93** will be restrained from further downward movement. For example, backside anti-extrusion rings **92**, **93** may land on shoulders **106** on the inner surface **16** of outer tubular **12** and outer diameter surface **18** of the inner tubular **14**. In alternative embodiments, a retainer ring or similar devise may be used instead.

By continuing to apply a downwards force to primary anti-extrusion rings **90**, **91**, downward facing surface **98** of inner backside anti-extrusion ring **92** engages and slides along upward facing surface **100** of outer backside anti-extrusion ring **93**. This causes the inner backside anti-extrusion ring **92** to move towards and come into contact with inner surface **16** of outer tubular **12** and outer backside anti-extrusion ring **93** to move towards and come into contact with outer diameter surface **18** of the inner tubular **14**. Backside anti-extrusion rings **92**, **93** will together then cover the full diameter of annulus **20**, limiting the downward expansion of backside seal rings **82**, **84**.

This downward force on primary anti-extrusion rings **90**, **91** will cause primary energizer **62** to move towards backside energizer **64**. This causes upward facing shoulders **83** of intermediate anti-extrusion ring to engage downward facing shoulders **85** of primary energizer **62**, and downward facing shoulder **87** of anti-extrusion rings **86**, **88** engage upward facing shoulders **89** of backside energizer **64**, forcing the intermediate outer anti-extrusion ring **88** to move towards inner surface **16** of outer tubular **12** and intermediate inner anti-extrusion ring **86** to move towards outer diameter surface **18** of the inner tubular **14**. Movement of the anti-extrusion rings **86**, **88** may be limited either by inner surface **16** of outer tubular **12** and outer diameter surface **18** of the inner tubular **14** respectively, or by the closed ends of energizers **62**, **64** contacting upper and lower surfaces of lateral portions **102**, **104** of anti-extrusion rings **86**, **88**.

The downward force on primary anti-extrusion rings **90**, **91** will additionally cause downward facing surface **94** of outside primary anti-extrusion ring **90** engages and slide along upward facing surface **96** of inner primary anti-extrusion ring **91**. This will result in inner primary anti-extrusion ring **90** to moving towards and coming into contact with outer diameter surface **18** of the inner tubular **14** and outer primary anti-extrusion ring **91** moving towards and coming into contact with inner surface **16** of outer tubular **12**. Primary anti-extrusion rings **90**, **91** will together then cover the full diameter of annulus **20**, limiting the upward expansion of primary seal rings **78**, **80**. A retaining mechanism, such as retaining ring **108** will be used to maintain the downward force on primary anti-extrusion rings.

Seal assembly **21** may be installed within annulus **20** with a interference between the inner surface **16** of outer tubular **12** and outer diameter surface **18** of the inner tubular **14**. The compression on the energizers **62**, **64** causes legs **68**, **70** of primary energizer **62** and legs **74**, **76** of backside energizer **64** to deflect inwardly, generating an outward radial elastic load. This will cause seal rings **80**, **84** to be compressed between inner surface **16** of outer tubular **12** and the energizers **62**, **64** respectively, and seal rings **78**, **82** to be compressed between outer diameter surface **18** of the inner tubular **14** and energizers **62**, **64**, respectively. The compressive forces causes plastic deformation of seal rings **78**, **80**, **82**, **84**, causing them to deform and become thinner and taller. The increase in height of seal rings **78**, **80** is contained to the space between the primary anti-extrusion rings **90**, **91** and the intermediate anti-extrusion rings **86**, **88**. The increase in height of seal rings **82**, **84** is contained to the space between the intermediate anti-extrusion rings **86**, **88** and the backside anti-extrusion rings **92**, **93**. The combination of the elastic deformation of energizers **62**, **64** and plastic deformation of seal rings **78**, **80**, **82**, **84** creates a constant elastic contact pressure at each of the sealing interfaces which does not diminish with time or load history or temperature, and creates a seal at low pressure and also possibly at high pressure.

Alternatively, the radial outward elastic load of energizers **62**, **64** may be created by the fluid pressure within grooves **66**, **72**, which applies an outward force on legs **68**, **70**, **74**, **76**, casing outward radial deflections of legs **68**, **70**, **74**, **76**. In the same manner as discussed above, this will cause seal rings **78**, **80**, **82**, **84** to be compressed between inner surface **16** of outer tubular **12** and the energizers **62**, **64**, and the outer diameter surface **18** of the inner tubular **14** and energizers **62**, **64**, respectively. The compressive forces causes plastic deformation of seal rings **78**, **80**, **82**, **84**, causing them to deform and become thinner and taller. The increase in height of seal rings **78**, **80** is contained to the space between the primary anti-extrusion rings **90**, **91** and the intermediate anti-extrusion rings **86**, **88**. The increase in height of seal rings **82**, **84** is contained to the space between the intermediate anti-extrusion rings **86**, **88** and the backside anti-extrusion rings **92**, **93**. The combination of the elastic deformation of energizers **62**, **64** and plastic deformation of seal rings **78**, **80**, **82**, **84** creates a constant elastic contact pressure at each of the sealing interfaces.

Seal rings **78**, **80**, **82**, **84** are formed of soft inelastic materials and may be for example, a soft metal such as lead, tin, silver, gold or tantalum, an inelastic thermoplastic, such as virgin polytetrafluoroethylene, filled polytetrafluoroethylene or polyetheretherketone, or other inert inelastic materials such as compression molded graphite. Seal rings **78**, **80**, **82**, **84** may alternatively be formed of other soft inelastic materials. An appropriate soft inelastic material will be selected so that seal rings **78**, **80**, **82**, **84** will flow readily into defects on the inner surface **16** of outer tubular **12** and the outer diameter surface **18** of the inner tubular **14** and create sufficient contact pressure on the surface of any such defect to create a seal when subjected to radial loading. Where there is no defect present the seal rings **78**, **80**, **82**, **84** will simply deform and flow upwards and downwards to fill the available space, while creating a seal on the defect free inner surface **16** of outer tubular **12** and the outer diameter surface **18** of the inner tubular **14**.

Energizers **62**, **64** are formed from material, such as steel or nickel or alloy thereof, that is strong enough to withstand the internal fluid pressure within the annulus **20** as well as any internal loads generated by the interference fit between the energizers **62**, **64**, the inner surface **16** of outer tubular **12** and outer diameter surface **18** of the inner tubular **14**, without undergoing significant plastic deformation, which could limit the load that could be applied to energizers **62**, **64** or cause failure of energizer **62**, **64** and thus cause the seal assembly **21** to fail. Energizers **62**, **64** must therefore be made from material with higher strength or that is harder than the material used to make the seal rings **78**, **80**, **82**, **84**.

In the drawings and specification, there have been disclosed a typical preferred embodiment of the disclosure, and although specific terms are employed, the terms are used in a descriptive sense only and not for purposes of limitation. The terms "vertical", "horizontal", "upward", "downward", "above", and "below" and similar spatial relation terminology are used herein only for convenience because elements of the current disclosure may be installed in various positions. Embodiments of this disclosure have been described in considerable detail with specific reference to these illustrated embodiments. It will be apparent, however, that various modifications and changes can be made within the spirit and scope of the disclosure as described in the foregoing specification. For example, although primarily illustrated in the context of a casing hanger landed within a modified high-pressure wellhead housing, one of ordinary skill in the art will recognize that the featured seal assembly and methods can be readily employed with respect to tubing within modified casing or other tubing.

What is claimed is:

1. A seal assembly for sealing an annulus between inner and outer wellhead members, the seal assembly comprising:

a U-shaped energizer ring formed of a high strength elastic metal material having inner and outer legs joined by a base at a lower end of the energizer ring, the energizer ring having a central axis;

an annular inner recess formed on an inward facing surface of the inner leg;

an inner diameter seal ring formed of an inelastic metal material, the inner diameter seal ring having an interior surface mounted to the inner recess;

an annular outer recess formed on an outward facing surface of the outer leg;

an outer diameter seal ring formed of an inelastic metal material, the outer diameter seal ring having an interior surface mounted to the outer recess; wherein

prior to insertion into the annulus, each of the seal rings has a radial width between the interior surface and an exterior surface of each of the seal rings that is less than an axial dimension from an upper edge to a lower edge of each of the seat rings;

each of the inner and outer legs has a lower base end that joins the base and an upper free end;

each of the inner and outer legs has an interior surface that faces towards the other leg and an exterior surface that faces away from the other leg;

the exterior surface of one of the inner and outer legs has a base portion that extends axially upward from proximate the base end, and a transition portion that extends axially downward from a location axially below a lower end of one of the seal rings to the base portion, the base portion being a cylindrical surface concentric with the axis and the transition portion being a conical surface; and

wherein, when the energizer ring is coaxially inserted in the annulus, the free ends of the inner and outer legs elastically deflect toward each other, causing the inner diameter seal ring to be compressively and permanently deformed into sealing contact with the inner wellhead member, and causing the outer diameter seal ring to be compressively and permanently deformed into sealing contact with the outer wellhead member.

2. The seal assembly of claim **1**, wherein:

each of the inner and outer legs has an enlarged portion proximate to the free end with a radial width greater than the radial width of the leg proximate to the base end; and

the inner recess and the outer recess are formed in the enlarged portions.

3. The seal assembly of claim **1**, wherein one leg is a longer leg and the other leg is a shorter leg such that the longer leg has an axial length that is greater than an axial length of the shorter leg.

4. The seal assembly of claim **1**, wherein:

each of the inner and outer legs has an enlarged portion proximate to the free end with a radial width greater than the radial width of the leg proximate to the base end; and

the exterior surface of at least one leg tapers gradually to the enlarged portion.

5. The seal assembly of claim **1**, wherein:

the exterior surface of each of the seal rings is cylindrical prior to insertion of the seal assembly into the annulus.

6. The seal assembly of claim **1**, wherein:

the exterior surface of at least one leg has a large radius of curvature extending from the free end towards the recess.

7. The seal assembly of claim **1**, wherein:

a largest radial width of at least one of the legs proximate the free end is less than an axial distance between the free end and the recess of the at least one of the legs.

8. The seal assembly of claim **1**, wherein the inner diameter seal ring and the outer diameter seal ring are formed of material selected from a group consisting of lead, tin, or silver.

9. The seal assembly of claim **1**, wherein:

the inner recess has grooves on a base of the inner recess;

the inner diameter seal ring engages the grooves of the inner recess and protrudes radially outward past the exterior surface of the inner leg;

the outer recess has grooves on a base of the outer recess; and

the outer diameter seal ring engages the grooves of the outer recess and protrudes radially outward past the exterior surface of the outer leg.

10. The seal assembly of claim **1**, wherein the interior surface of each of the inner and outer legs has a first portion that extends axially upward from proximate the base end to a location axially below a lower end of the seal ring, and a second portion that extends axially downward from proximate the free end to the first portion, the first portion being a cylindrical surface parallel to the axis and the second portion being a conical surface.

11. A wellhead assembly comprising:

an outer wellhead member having a bore and an axis, the outer wellhead member further having a tapered outer wellhead shoulder defined by a change in inner diameter of the outer wellhead member from a region with a smaller inner diameter to a region with a larger inner diameter;

an inner wellhead member located in the bore and defining an annulus between the inner and outer wellhead members, the inner wellhead member further having a tapered inner wellhead shoulder defined by a change in outer diameter of the inner wellhead member from a region with a smaller inner diameter to a region with a larger inner diameter;

a U-shaped energizer ring formed of an elastic metal material and comprising a base, and inner and outer legs joined by and extending axially from the base to a free end that bias in opposing radial directions respectively against the inner and outer wellhead members;

the inner leg having a base end and a free end, and an inward facing surface with an annular inner band located on and protruding inward from the inward facing surface of the inner leg proximate the free end;

an annular inner recess formed in the inner band;

an annular inner diameter seal ring formed of an inelastic metal material located in the inner recess;

the outer leg having a base end and a free end, and an outward facing surface with an annular outer band located on and protruding outward from the outward facing surface of the outer leg proximate the free end;

an annular outer recess formed in the outer band;

an annular outer diameter seal ring formed of an inelastic metal material located in the outer recess;

an open slot between the legs; wherein

when the energizer ring is coaxially inserted in the annulus, the free ends of the inner and outer legs elastically deflect toward each other, causing the inner diameter seal ring to be compressively and permanently deformed into sealing contact with the inner wellhead member, and causing the outer diameter seal ring to be compressively and permanently deformed into sealing contact with the outer wellhead member; and wherein

the energizer ring is located within the annulus axially between the outer wellhead shoulder and the inner wellhead shoulder.

12. The wellhead assembly of claim **11**, wherein an axial length of the band on the inner leg and on the outer leg have a cylindrical end surface concentric with the axis.

13. The wellhead assembly of claim **11**, wherein the inner leg has an axial length that is shorter than an axial length of the outer leg.

14. The wellhead assembly of claim **11**, wherein the inward facing surface of the inner leg tapers gradually to the inner band.

15. The wellhead assembly of claim **11**, wherein the outward facing surface of the outer leg has an undercut recess at a junction of the outward facing surface and the outer band.

16. The wellhead assembly of claim **11**, wherein an outer surface of the outer band has a large radius of curvature extending from the free end towards the recess.

17. The wellhead assembly of claim **11**, wherein an outer surface of both the outer band and the inner band has a large radius of curvature extending from the free end towards the recess.

18. The wellhead assembly of claim **11**, wherein:

the inner recess has grooves on a base of the inner recess;

the inner diameter seal ring engages the grooves of the inner recess and protrudes radially outward past the exterior surface of the inner band;

the outer recess has grooves on a base of the outer recess; and

the outer diameter seal ring engages the grooves of the outer recess and protrudes radially outward past the exterior surface of the outer band.

19. The wellhead assembly of claim **11**, wherein the inner wellhead shoulder is an upward facing shoulder located axially above the energizer ring and the outer wellhead shoulder is a downward facing shoulder located axially below the energizer ring.

20. A method for sealing an annulus between inner and outer wellhead members, the method comprising the steps of:

(a) providing a seal assembly that comprises a U-shaped energizer ring formed of a high strength elastic metal material having:

a central axis;

inner and outer legs joined by a base at a lower end of the energizer ing and and an upper free end;

an annular inner recess formed on an inward facing surface of the inner leg, and an inner diameter seal ring formed of an inelastic metal material mounted to the inner recess;

an annular outer recess formed on an outward facing surface of the outer leg, and an outer diameter seal ring formed of an inelastic metal material mounted to the outer recess,

(b) inserting the seal assembly into the annulus so that the free ends of the inner and outer legs elastically deflect toward each other, causing the seal rings contact inner and outer surfaces of the annulus, plastically deforming the seal rings into sealing engagement between the legs and the inner and outer surfaces by a spring force in the legs; and

(c) landing the energizer ring within the annulus axially between a tapered outer wellhead shoulder and tapered inner wellhead shoulder, the outer wellhead shoulder defined by a change in inner diameter of the outer wellhead member from a region with a smaller inner diameter to a region with a larger diameter, and the inner wellhead shoulder being defined by a change in outer diameter of the inner wellhead member from a region with a smaller inner diameter to a region with a larger inner diameter.

21. The method of claim **20**, wherein each of the inner and outer legs has an enlarged portion proximate to the free end with a radial width greater than the radial width of the leg proximate to the base end, the exterior surface of one leg tapering gradually to the enlarged portion and the exterior surface of the other leg having a large radius of curvature extending from a free end of the leg towards the recess, wherein the step of inserting the seal assembly into the annulus includes:

slidingly engaging the gradual taper with a surface of one of the wellhead members; and

slidingly engaging the large radius of curvature with the other of the wellhead members.

22. The method of claim **20**, wherein the exterior surface of both the inner and outer legs having a large radius of curvature extending from a free end of the leg towards the recess, wherein the step of inserting the seal assembly into the annulus includes:

slidingly engaging the large radius of curvature of the outer leg with the outer wellhead member; and

slidingly engaging the large radius of curvature of the inner leg with the inner wellhead member.

23. The method of claim **18**, wherein the inner wellhead shoulder is an upward facing shoulder located axially above the energizer ring and the outer wellhead shoulder is a downward facing shoulder located axially below the energizer ring, wherein step (b) further comprises engaging at least one of the upward facing shoulder and the downward facing shoulder with a portion of the energizer ring to apply the spring force in the legs.

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